NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

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This final report is part of the Leapfrog Technology to Standardize Equipment and System Installations project. The project consists of a manual including ten deliverables, a complete set of standards for foundations and hangers, a scantling selection computer program using Microsoft Excel, and this final report.

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ABSTRACT

Leapfrog Technology is defined within this project as a holistic, cost effective approach to combining and applying innovative yet simple products and processes concurrently throughout various departments including engineering, fabrication shops, and production stages of construction.

The present technology for designing, manufacturing, and installing equipment foundations and systems is labor intensive and is often on the critical path of ship construction. The lowest total installed costs will be achieved through the streamlining or elimination of these labor-intensive tasks.

This project will give the tools, products and approach necessary to minimize the completely installed costs for foundations and hangering systems in the form of a manual including ten deliverables, a complete set of standards for foundations and hangers, a scantling selection computer program using Microsoft Excel, and this final report.

1. INTRODUCTION

The objective of this manual is to develop a set of equipment and distributive system installation standards that result in the lowest possible installed cost. These standards are to be parametric in nature and lend themselves to inclusion into a product modeling system.

Traditionally the design of foundations and hangering systems was based on qualitative requirements that have been developed from what is known as the principles of good sound shipbuilding practices. Line organizations in most shipyards have been conditioned over the years to properly implement the specifications. The basis or rationale for much of the specifications has been lost over time. It is difficult to attempt to initiate changes in design to reduce costs when engineers and designers will not risk departing from traditional ways because they are fearful of violating unknown criteria. Guidance on designs provided by engineering management organizations usually instructs the designer/engineer to use designs developed on prior ships as a basis for new designs. In this way previous designs are perpetuated and little or no innovation is permitted in the development of new designs.

By applying leapfrog technology, which is innovative yet simple products and processes concurrently throughout all departments within the shipyard, significant reduction of man-hours and construction lead times can be achieved in the area of foundations and hangering systems.

2. ENGINEERING AND DESIGN

2.1. INTEGRATION OF ENGINEERING DESIGN AND ANALYTICAL TASKS

Traditionally, design and analytical tasks are performed separately where there is little or no interaction between the two. The ultimate goal to reduce and streamline engineering costs and cycle time would have the design and analytical tasks combined into an interactive environment, such as the 3-D computer model. Embedding spreadsheet calculations within the 3-D model would combine physical design with analytical computations. What normally are separate and sequential processes could become one parallel process performed by one individual. This would give the following benefits:

- Combining two sequential tasks into one parallel task.
- Reduction in engineering manpower and cycle time.
- Eliminates repetitive engineering calculations that need to be performed and reduces the chance of human error.

The ultimate scenario would be to have intelligent 3-D parametric objects (i.e., foundations, hangers, and racking systems) which would update automatically in response to a design change. For example, if a pipe rack had two additional 10-inch diameter pipes added to the racking system, the change in the model would trigger off calculations being performed in the background which would determine the new required scantlings to support the additional loading. This might then automatically change the racking system scantlings from a 2 x 2 x 1/4 to a 3 x 3 x 1/4 angle bar support within the 3-D model.

2.2. HANGERING SYSTEM SCANTLING SELECTION PROGRAM AND SPREADSHEETS

A second option to integrating engineering design and analytical tasks would be to have the scantling spreadsheet calculations and the 3-D model as separate entities. This second approach was chosen for this project because U.S. shipyards use a variety of 3-D modeling systems. Presently, various computer 3-D modeling companies are discussing the development of embedded expert systems into their 3-D modeling systems.

As part of this NSRP project, a scantling selection computer program has been developed using Microsoft Excel software. The outputs include spreadsheets that aid engineers and designers in determining the required hangering system scantling size for the most common scenarios on-board a ship. Spreadsheets have been developed for single run hangers, single run hangers with bracing, racking systems with legs and structural attachments, and goal post racking systems with variable number of legs. These scenarios can be calculated using different configurations. These include forward and aft runs supported horizontally, athwartship runs supported horizontally, vertical runs mounted to longitudinal, and athwartship bulkheads. These spreadsheets determine the minimum section modulus and defaults to the required scantling size. The scantling selection, which can be chosen, should reflect the raw material stock carried by the particular shipyard.

In the past there was no simple and consistent manner to determine scantling sizes, therefore, most racking systems were overdesigned, driving up the total installed costs. The spreadsheet ensures that the scantlings selected are adequate without being overly conservative Hanger Scantling Selection Spreadsheet Summary

The racks.xls spreadsheet was developed to assist in the selection of pipe racks scantlings for a variety of situations. Although many configurations are covered, some unique installations will have to be analyzed separately. The sheet consists of an input box, output box, a scantling chart, calculation section, and several drawings. An attempt was made to create a product that is user friendly and easily updated if different criteria is to be used. The following is a line by line description of the spreadsheet.

2.2.1.

Allowable Stress (psi) - This value represent the user defined maximum allowable stress in the pipe rack scantlings. This value is based on the scantling material. A commonly used value for steel is 34,000 psi. Adjustments to this value can produce varying factors of safety (i.e., 17,000 psi would create a factor of safety of 2)

# of Pipes (#) - This value represent the range of outfitting systems (pipes) on the rack. The rack outfitting systems can range anywhere from 1 to 15. If necessary, the chart can be altered to accommodate additional systems. This would require adding additional rows to the pipe charts in both the input box and calculation box. The total weight line in the calculation box would also change to reflect the added rows. In a double tier situation, it would be necessary to run two different calculations. The first calculation would be for the outer tiers rack and legs. The second calculation would be for the inner tier rack and legs. For the second calculation it would be necessary to add the weight of the outer tier as an additional weight.

Standoff (inches) This value represent the distance between the pipes and the hull structure or simply the leg length.

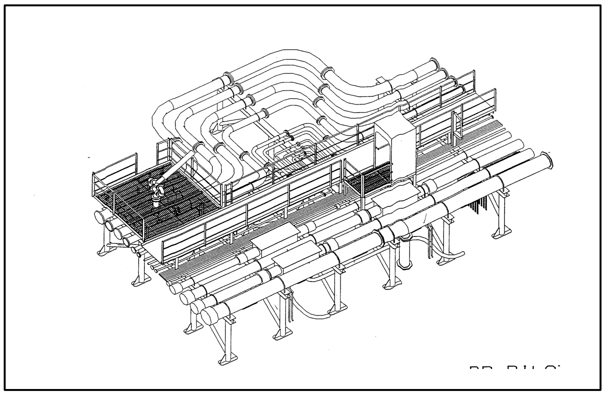
Length of Rack (inches) This value represents the width of the rack or the length of the pipe supporting the scantling. In the cantilever case, there is only rack and no leg.

Gz, Gx, Gy These values represents the G-force inputs to the to the pipe rack. The G-load chart indicates proper orientations. The values are a function of location in the ship and the ship s motion.

# of Legs (#) This value represent the number of rack legs. This value does not include attachments to the ship structure.

# of Structural Attachments (#) This value represent the number of attachments to the ship structure. This value should not include legs.

Spreadsheet Detailed Instructions - The manual of instructions for stud spreadsheets & scantling selection spreadsheet shows detailed instructions on using the spreadsheets in this project.



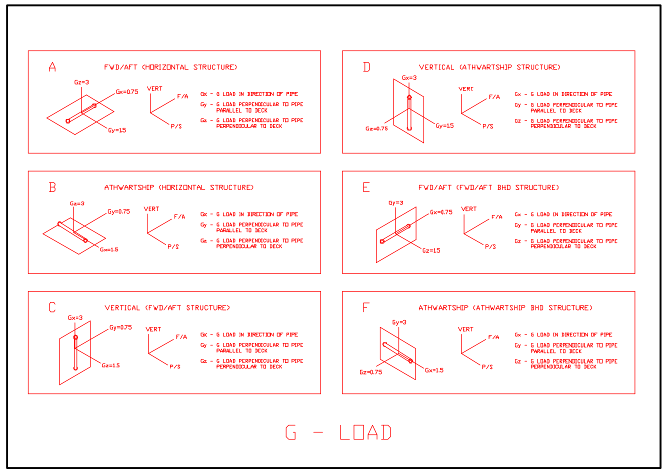


Figure 1 Typical Racking System Sample

INPUT RACKING SYSTEM DATA			OUTFITTING SYSTEMS INPUT DATA					
			PIPE INPUT	**PIPE WT/FT (WITH CONTENTS) (LBS/FT)**	**ADDITIONAL WEIGHT (VALVES, ETC.) (LBS.)**	**ACTUAL PIPE HANGER SPACING (FT)**	**START-UP FACTOR (MULTIPLIER**	**RACKING SYSTEMS**
ALLW. STRESS	34000	PSI	PIPE 1	201.80	0.00	13.00	1.00	18 IG
# OF PIPES	13	#	PIPE 2	102.10	0.00	13.00	1.00	12 CONDUIT
STANDOFF	82.00	IN	PIPE 3	102.10	0.00	13.00	1.00	12 CONDUIT
LENGTH OF RACK	216	IN	PIPE 4	5.12	0.00	6.50	1.00	2 AL01
G LOAD CASE (A-F)	A		PIPE 5	5.12	0.00	6.50	1.00	2 HV01
GZ	3.00	G'S	PIPE 6	5.12	0.00	6.50	1.00	2 HV01
GX	0.75	G'S	PIPE 7	10.80	0.00	6.50	1.00	3 DO
GY	1.50	G'S	PIPE 8	16.33	0.00	6.50	1.00	4 CO
NUMBER OF LEGS	4	#	PIPE 9	50.29	7.00	6.50	1.00	8 FO
# OF STR. ATTACH	0	#	PIPE 10	74.73	0.00	13.00	1.00	10 AF
INPUT CASE #	5	#	PIPE 11	74.73	7.00	13.00	1.00	10 FM
CASE 1	CANTILEVER		PIPE 12	102.10	7.00	13.00	1.00	12 TC
CASE 2	CANT W/ BRACE (STR ATT = 1)		PIPE 13	200.00	7.00	6.50	1.00	WALKWAY
CASE 3	2 STRUC ATT., NO LEGS		-	0.00	7.00	0.00	1.00	-
CASE 4	STRUC ATTS. PLUS LEGS		-	0.00	7.00	0.00	1.00	-
CASE 5	ONLY LEGS	OK						**

Table 1 Rack and Outfitting Input Data

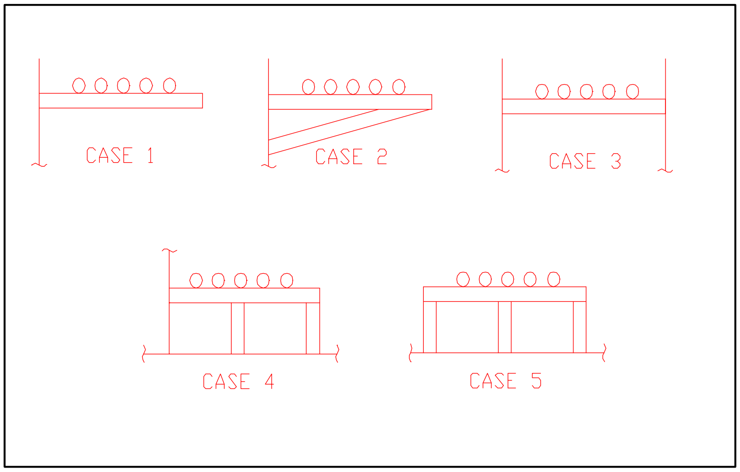


Figure 2 Five Input Case Scenerios

OUTPUT RACKING SYSTEM DATA			
RACK DATA		**LEG DATA**	
RACK LENGTH (IN)	216	LEG LENGTH (IN)	82.00
RACK REQD SM (IN^3)	5.533	LEG REQD SM	12.603
ANGLE	7X4X1/2	ANGLE	#N/A
ANGLE SM (IN^3)	5.810	ANGLE SM (IN^3)	0.000
ANGLE I (IN^4)	26.7	ANGLE I (IN^4)	#N/A
ANGLE FREQ (HZ)	1.89	ANGLE FREQ (HZ)	#N/A
CHANNEL	8X2-1/4X11.5#	CHANNEL	12X1-1/2X10.6#
CHANNEL SM (IN^3)	8.140	CHANNEL SM (IN^3)	13.715
CHANNEL I (IN^4)	32.56	CHANNEL I (IN^4)	82.29
CHANNEL FREQ (HZ)	2.09	CHANNEL FREQ (HZ)	3.54
		PIPE	8 SCH 80
		PIPE SM (IN^3)	24.514
		PIPE (IN^4)	105.716
		PIPE FREQ (HZ)	4.02

Table 2 Output Scantling Data

The tables above represent the minimum scantling requirements for the legs and rack to support the outfitting systems.

CALCULATIONS

	PIPE WT/FT (WITH CONTENTS) (LBS/FT)	ADDITIONAL WEIGHT (VALVES, ETC.) (LBS.)	ACTUAL PIPE HANGER SPACING (FT)	START-UP FACTOR (MULTIPLIER)	TOTAL WEIGHT (LBS)	RACK SCANTLINGS		LEG SCANTLINGS	
						RACK LENGTH	216.00	LEG LENGTH	82.00
PIPE 1	201.80	0.00	13.00	1.00	2623.4	TOTAL WEIGHT	10451.35	TOTAL WEIGHT	10451.35
PIPE 2	102.10	0.00	13.00	1.00	1327.3	W ZDIR (LBS)	10451.35	W VERT (LBS)	10451.35
PIPE 3	102.10	0.00	13.00	1.00	1327.3	W XDIR (LBS)	2612.84	W LONG (LBS)	2612.84
PIPE 4	5.12	0.00	6.50	1.00	33.3	W YDIR (LBS)	5225.68	W TRAN (LBS)	5225.68
PIPE 5	5.12	0.00	6.50	1.00	33.3	W ZDIR (LB/IN)	145.16		
PIPE 6	5.12	0.00	6.50	1.00	33.3	W XDIR (LB/IN)	36.29		
PIPE 7	10.80	0.00	6.50	1.00	70.2	W YDIR (LB/IN)	30.0072.58		
PIPE 8	16.33	0.00	6.50	1.00	106.1				
PIPE 9	50.29	7.00	6.50	1.00	326.9	CASE 1 Z MOMENT	188124.30		
PIPE 10	74.73	0.00	13.00	1.00	971.5	CASE 1 X MOMENT	94062.15		
PIPE 11	74.73	7.00	13.00	1.00	971.5	CASE 1 Y MOMENT	188124.30		
PIPE 12	102.10	7.00	13.00	1.00	1327.3	CASE 2 Z MOMENT	94062.15		
PIPE 13	200.00	7.00	6.50	1.00	1300.0	CASE 2 X MOMENT	47031.08		
N/A	0.00	7.00	0.00	1.00	0.0	CASE 2 Y MOMENT	94062.15		
N/A	0.00	7.00	0.00	1.00	0.0	CASE 3 X MOMENT	62708.10		
						CASE 3 Y MOMENT	15677.03		
						CASE 4 Z MOMENT	94062.15	CASE 4 Z MOMENT	214252.68
						CASE 4 X MOMENT	94062.15	CASE 4 X MOMENT	214252.68
						CASE 5 Z MOMENT	194062.15	CASE 5 Z MOMENT	428505.35
						CASE 5 X MOMENT	23515.54	CASE 5 X MOMENT	214252.68
						CASE 5 Y MOMENT	188124.30	CASE 5 Y MOMENT	428505.35
						RACK MOMENT ZDIR	94062.15	LEG MOMENT ZDIR	428505.35
						RACK MOMENT XDIR	23515.54	LEG MOMENT XDIR	214252.68
						RACK MOMENT YDIR	188124.30	LEG MOMENT	428505.35

CALCULATIONS									
	PIPE WT/FT (WITH CONTENTS) (LBS/FT)	**ADDITIONAL WEIGHT (VALVES, ETC.) (LBS.)**	**ACTUAL PIPE HANGER SPACING (FT)**	**START-UP FACTOR (MULTIPLIER)**	**TOTAL WEIGHT (LBS)**	**RACK SCANTLINGS**		**LEG SCANTLINGS**	
								YDIR	
						MAX RACK MOM	188124.30	MAX LEG MOM	428505.35
						RACK REQD SM	5.533	LEG REQD SM	12.603

Table 3 Scantling calculation data

AVAILABLE SCANTLINGS (WHICH MEET INPUT REQUIREMENTS)							
ANGLE	**RACK SM**	**LEG SM**	**CHANNELS**	**RACK SM**	**LEG SM**	**PIPE**	**LEG SM**
1 X 1 X 1/8	N/A	N/A	RTD1.624X.625X14 GA	N/A	N/A	1/2" SCH 80	N/A
RTD 12 GA ANGLE	N/A	N/A	1-1/4 X 1/2 X 1.0 #	N/A	N/A	3/4" SCH 80	N/A
1 X 1 X 1/4	N/A	N/A	RTD1.624X.625X3/16	N/A	N/A	1" SCH 80	N/A
1-1/4 X 1-1/4 X 3/16	N/A	N/A	2 X 1 X 2.32 #	N/A	N/A	1-1/4" SCH 80	N/A
1-1/2 X 1-1/2 X 1/8	N/A	N/A	3 X 1-5/8 X 6.0 #	N/A	N/A	1-1/2" SCH 80	N/A
RTD 3/16 ANGLE	N/A	N/A	4 X 1-5/8 X 7.25 #	N/A	N/A	2" SCH 80	N/A
1-1/2 X 1-1/2 X 1/4	N/A	N/A	5 X 1-3/4 X 9.0 #	N/A	N/A	2-1/2" SCH 80	N/A
2 X 2 X 1/4	N/A	N/A	6 X 2 X 10.5 #	N/A	N/A	3" SCH 80	N/A
2 X 2 X 3/8	N/A	N/A	8 X 2-1/4 X 11.5 #	8.140	N/A	4" SCH 80	N/A
2-1/2 X 2-1/2 X 5/16	N/A	N/A	6 X 3-1/2 X 15.3 #	8.368	N/A	5" SCH 80	N/A
3 X 3 X 1/4	N/A	N/A	10 X 1-1/2 X 8.4 #	8.909	N/A	6" SCH 80	N/A
3 X 3 X 3/8	N/A	N/A	8 X 3 X 18.7 #	11.000	N/A	8" SCH 80	25.514
4 X 3 X 1/4	N/A	N/A	9 X 2-1/2 X 15.0 #	11.300	N/A	10" SCH 80	45.552
4 X 3-1/2 X 5/16	N/A	N/A	12 X 1-1/2 X 10.6 #	13.715	13.715	12" SCH 80	74.526
4 X 3 X 3/8	N/A	N/A	10 X 3-1/2 X 25.3 #	18.200	18.200	14" SCH 80	98.188
5 X 3-1/2 X 5/16	N/A	N/A	12 X 3 X 20.7 #	21.500	21.500		
4 X 4 X 1/2	N/A	N/A	13 X 4 X 35.0 #	37.106	37.106		
5 X 3-1/2 X 3/8	N/A	N/A					
6 X 4 X 5/16	N/A	N/A					
6 X 3-1/2 X 3/8	N/A	N/A					
6 X 4 X 3/8	N/A	N/A					
6 X 4 X 1/2	N/A	N/A					

AVAILABLE SCANTLINGS (WHICH MEET INPUT REQUIREMENTS)							
ANGLE	**RACK SM**	**LEG SM**	**CHANNELS**	**RACK SM**	**LEG SM**	**PIPE**	**LEG SM**
7 X 4 X 3/8	N/A	N/A					
7 X 4 X 1/2	5.810	N/A					
8 X 4 X 1/2	7.490	N/A					
9 X 4 X 1/2	9.340	N/A					

Table 4 Acceptable scantling, which meets requirements from calculations.

LOOKUP CHART SECTION MODULUS AND INERTIA

SM	SCANTLING	INERTIA	SM	SCANTLING	INERTIA	SM	SCANTLING	INERTIA
0.031	1 X 1 X 1/8	0.022	0.093	RTD1.624X.625X14 GA	0.077	0.048	1/2" SCH 80	0.020
0.044	RTD 12 GA ANGLE	0.044	0.165	1-1/4 X 1/2 X 1.0 #	0.103	0.085	3/4" SCH 80	0.045
0.056	1 X 1 X 1/4	0.037	0.189	RTD1.624X.625X3/16	0.155	0.161	1" SCH 80	0.106
0.071	1-1/4 X 1-1/4 X 3/16	0.061	0.543	2 X 1 X 2.32 #	0.543	0.291	1-1/4" SCH 80	0.242
0.072	1-1/2 X 1-1/2 X 1/8	0.078	1.380	3 X 1-5/8 X 6.0 #	2.070	0.412	1-1/2" SCH 80	0.391
0.075	RTD 3/16 ANGLE	0.073	2.290	4 X 1-5/8 X 7.25 #	4.580	0.731	2" SCH 80	0.868
0.134	1-1/2 X 1-1/2 X 1/4	0.139	3.560	5 X 1-3/4 X 9.0 #	8.900	1.339	2-1/2" SCH 80	1.924
0.247	2 X 2 X 1/4	0.348	5.060	6 X 2 X 10.5 #	15.180	2.225	3" SCH 80	3.894
0.351	2 X 2 X 3/8	0.479	8.140	8 X 2-1/4 X 11.5 #	32.560	4.271	4" SCH 80	9.611
0.482	2-1/2 X 2-1/2 X 5/16	0.849	8.368	6 X 3-1/2 X 15.3 #	25.104	7.432	5" SCH 80	20.671
0.577	3 X 3 X 1/4	1.240	8.909	10 X 1-1/2 X 8.4 #	44.545	12.224	6" SCH 80	40.491
0.833	3 X 3 X 3/8	1.760	11.000	8 X 3 X 18.7 #	44.000	24.514	8" SCH 80	105.716
1.000	4 X 3 X 1/4	2.770	11.300	9 X 2-1/2 X 15.0 #	50.850	45.552	10" SCH 80	244.844
1.260	4 X 3-1/2 X 5/16	3.560	13.715	12 X 1-1/2 X 10.6 #	82.290	74.526	12" SCH 80	475.104
1.460	4 X 3 X 3/8	3.960	18.200	10 X 3-1/2 X 25.3 #	91.000	98.188	14" SCH 80	687.319
1.940	5 X 3-1/2 X 5/16	6.600	21.500	12 X 3 X 20.7 #	129.000			
1.970	4 X 4 X 1/2	5.560	37.106	13 X 4 X 35.0 #	241.190			
2.290	5 X 3-1/2 X 3/8	7.780						
2.790	6 X 4 X 5/16	11.400						
3.240	6 X 3-1/2 X 3/8	12.900						
3.320	6 X 4 X 3/8	13.500						
4.330	6 X 4 X 1/2	17.400						
4.440	7 X 4 X 3/8	20.600						
5.810	7 X 4 X 1/2	26.700						
7.490	8 X 4 X 1/2	38.500						
9.340	9 X 4 X 1/2	53.200						

******* IMPORTANT INFORMATION REGARDING THE USE OF THIS SPREADSHEET *******

ALLOWABLE STRESS IS INPUT BY THE DESIGNER TO ACCOUNT FOR ANY FACTOR OF SAFETY. FOR EXAMPLE, IF THE YIELD STRESS IS 34,000 AND A FACTOR OF SAFETY OF 2 IS DESIRED, ALLOWABLE STRESS SHOULD BE INPUT AS 17,000. G-LOADS ARE WORST CASE AT SEA CONDITIONS. IT IS ASSUMED THAT A TANKER WILL NOT EXPERIENCE A G-LOAD OF 3 SO THERE IS AN IMPLIED FACTOR OF SAFETY HERE. SCANTLINGS ARE CHOSEN BY THE MAXIMUM BENDING MOMENT ENCOUNTERED IN THREE DIFFERENT PLANES (X,Y,Z) DUE TO THE PIPE WEIGHTS AND THE LOCAL G-FORCES APPLIED. A START-UP FACTOR IS INCLUDED TO ACCOMMODATE FOR ANY ADDITIONAL FORCES INDUCED UNDER CIRCUMSTANCES SUCH AS THE STARTING UP OF THE PLANT.

Table 5 Available scantling data. (Represents the raw material stock carried by the shipyard and the section modulus and inertia data for each shape).

2.3. THE 3-D PRODUCT MODEL

The 3-D model represents the key design tool to this project. Traditionally, foundation and hangering systems have been shown as a two-dimensional overlay onto the 3-D model production information. Having all foundations and hangering systems modeled is essential to achieving major improvements in producibility. Complete 3-D modeling can provide the following benefits and outputs:

- Ensure an interference free design.

  As part of this project, a root cause analysis study was performed to determine the highest rework causes in foundation and hangering system installation. This study revealed that interference s and material inaccuracies are the highest causes of rework within production. Rework must be considered when determining the completely installed cost of any product.

- Automatic downloading of the parts from the 3-D model to the yard material control and procurement system (Bill of Material).

  This is an elemental but essential step in reducing the total installed cost. A manual material take-off from any 3-D model is 100% non-value-added. There is a huge amount of rework and non-value added tasks involved in engineering and production when employing a manual material take-off system.

- Numerically-controlled (NC) layout marking on the deck plates.

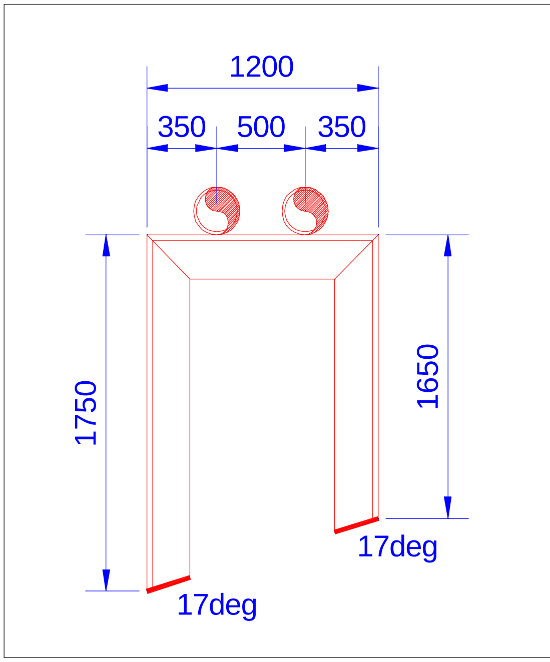
  This can be obtained by downloading information from the 3-D model to the NC burning machine tapes. This eliminates manual layout in production, which in some shipyards may be on the critical path.

- Foundation and multi-hanger system sketches with exact cut lengths can be obtained automatically.

  One key factor to reduce over all cycle time for ship construction, with regard to outfitting, is to focus on installation only and not fabrication. Fabrication should be driven back to the shops and be taken off the on-block critical path. Therefore, it is key that these stages of construction are provided with material that is available for installation and not fabrication. There can be a high degree of confidence that a part will fit in the required installation when coming from the model as opposed to free hand sketches, especially with complex parts.

  An example of this pre-fabrication is providing hangering systems, which do not require measuring and trimming to suit in the field. Hangering sketches can be done an output of the 3-D model as shown in Figure 3.

Sketch of pipe support



Material List		
L#	100*100*10	4450 mm
UB	UB1_200	2 ea
UN	UN1_200	4 ea
Paint	U2	
Position	X	FR67+500
	Y	700(STBD)
	Z	1500 ABL
Weight	325 Kg	
Name	ES_PPSPT_B01_005	

Figure 3 Pipe Support Sketch

2.4. STANDARDS

A simplified approach is to use the same parts in all standards across all trades as far as practical. The complete set of standards for foundations and hangers are included in Section 7 of the accompanying manual. The benefits are as follows:

- Production and Engineering become accustomed to fewer parts.
- Minimize hand-offs between trades.
- Stocking less parts which minimizes storage requirements.
- Vendors now have the ability to mass-produce identical parts for a lower cost.
- Elimination of labor intensive fabrication tasks.
- Minimizing labor-intensive installation tasks.
- Reduce total installed costs, which includes engineering costs, material cost, fabrication cost, and installation cost.

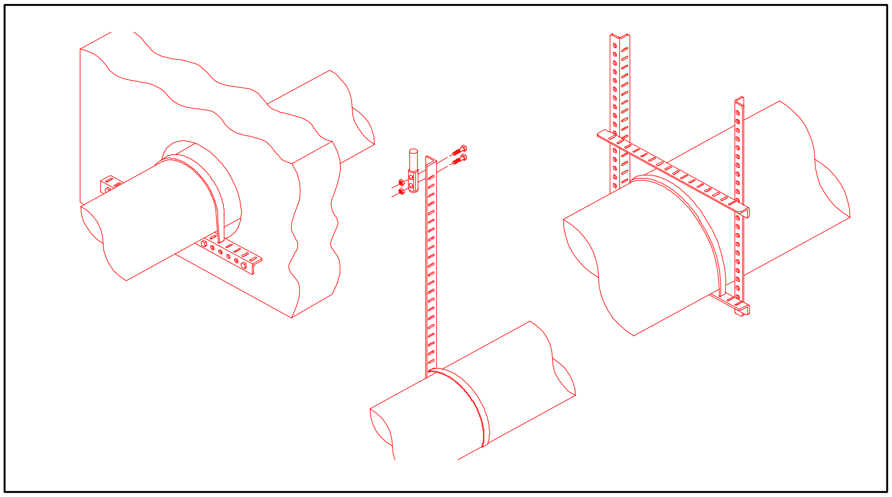


Figure 4 RT&D Interchangeable Ventilation Hangering System

The ventilation hankering system above shows the same standoff being utilized in a variety of configurations. This system is extremely flexible, easy to install, and cost effective.

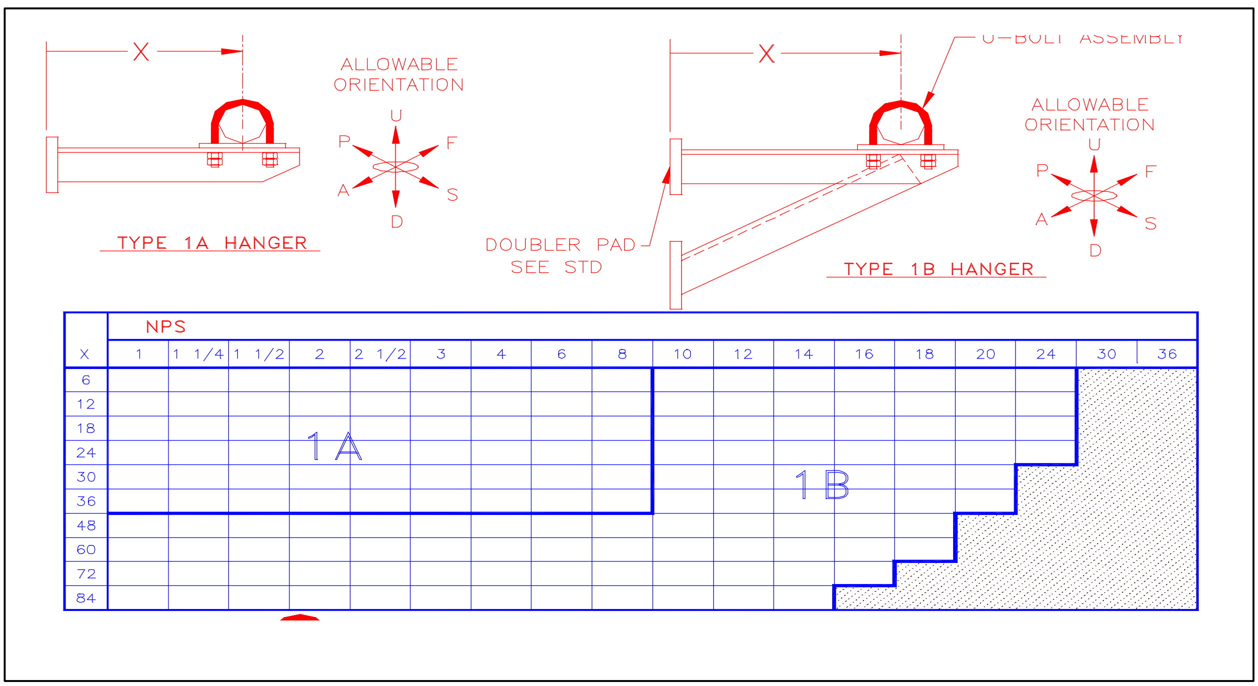


Figure 5 U-Bolt Standard (Scantlings Determined Using Spreadsheet Method)

This hanger is an excerpt from the standards shown in section 7 of the manual. The scantlings requirements were determined using the scantling selection spreadsheet also shown in section 7 of the manual.

2.5. FAMILY OF FOUNDATION TYPES

The development of revolutionary standards for H, M & E equipment and systems installations that will permit rapid modular assembly will facilitate the construction of the hull modules by reducing the labor time and cost in both the Hot pre-outfit and Cold outfit phases of construction. This exploratory research and development effort will focus on the development of techniques, methods, and standards that will facilitate the shifting of H, M & E outfit of foundations and systems installations from the labor intensive Hot pre-outfit construction practice to the considerably more efficient Cold outfit assembly line practice.

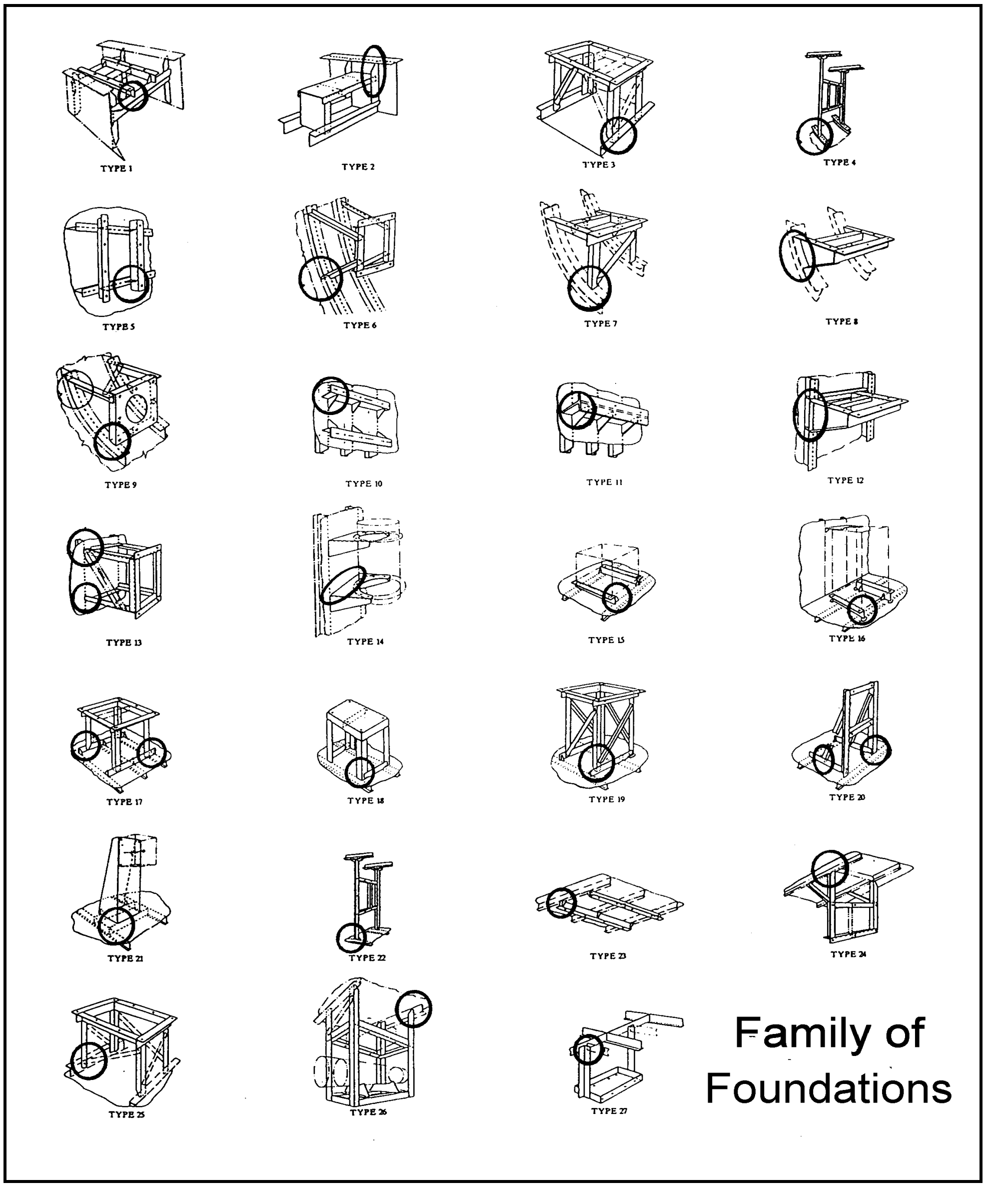


Figure 6 Family of Foundations

2.6. CONCURRENT ENGINEERING

Forming of a cross-functional team which represents all functional groups which can affect the products cost is essential to achieving the lowest possibly installed cost and to minimize sub-optimization. Defining the groups goal of achieving the lowest installed cost early and running pilots to verify predictions creates a system, which is extremely effective.

3. MANUFACTURING

3.1 RAW MATERIAL COSTS

The selection of raw material is important in that commonly used shapes should be used and applied consistently throughout the standards. A common error would be to specify an unusual shape or type of material on an engineering drawing with no thought to availability or material cost. Being cognizant of this simple fact can help hold down the cost of a ship set of standard foundation and hangering systems. For example, the raw material shown on the Hangering Scantling selection program are those carried in stock only. The user shipyard should replace their in-house stocked steel material with what is shown in the spreadsheet. An effort should be used to minimize the in-house selection. Shipyards should also be aware of the material used by their subcontractors, as it will drive up the costs if a material type is specified which is not carried in stock by the subcontractor.

3.2 FABRICATION COSTS

Various studies were conducted to investigate fabrication costs. They involved Industrial Engineering type time studies (breaking down each incremental step in the process) within the shipyard and main subcontractors. The following is a simple example of how this process was performed and the resulting reduction in fabrication times and other benefits. The figures below show the progression when applying the producibility features to a product. This is a simple example of what would appear to be an elementary way to do business. Labor-intensive standards being fabricated repeatedly without much thought to the fabrication time is common place. This change in design will also minimize the engineering work content by eliminating the lofting and simplifying the detailed design requirements. Simple producibility features, such as this, can be applied with significant results. By minimizing the production steps, fabrication time was reduced from 5.45 hours to 1.24 hours on this part.

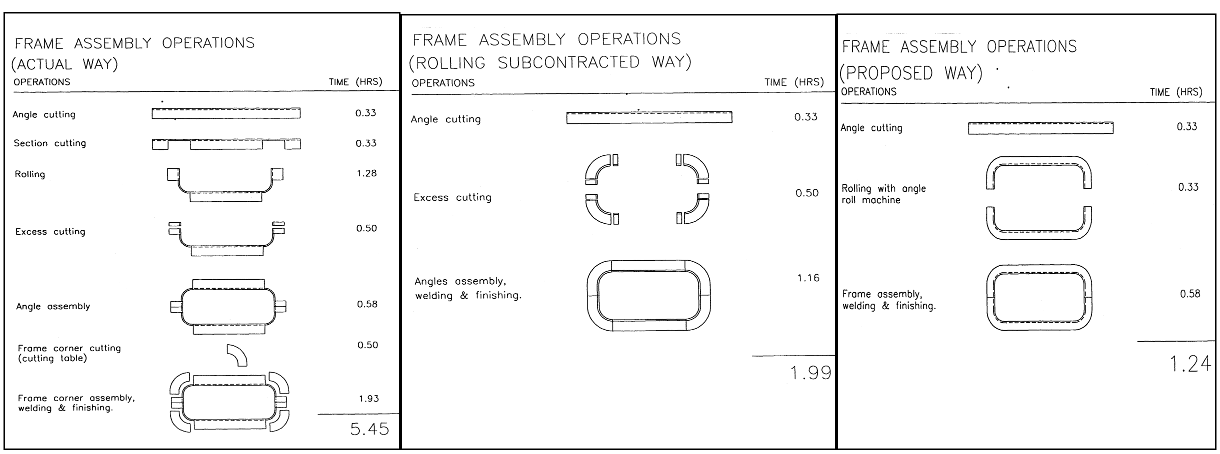


Figure 7 Foundation Frame Labor Intensive Part Easily Produced Part

4. INSTALLATION

4.1. INSTALLATION COSTS

Various studies were done as part of this NSRP project to investigate installation costs. Similarly to the fabrication time studies the complete installation process is broken down and flow-charted for identification and elimination of non-value added tasks. Below is a comparative analysis of different types of single-run hangering systems that were being evaluated for use. It is important to do real time pilot studies using a large enough quantity to be comfortable with the results. There are often many factors that may skew these results. It is important to recognize and understand these skewing factors. Running a large quantity of the proposed products through the time studies will minimize these factors. It is also important to observe the installation and take notes on key points.

The tables below show the comparative analysis technique that was used in determining the preferred installation type for inclusion into the total installed cost.

HANGER #1 INSTALLATION TASKS	SAMPLE 1 (SECONDS)	SAMPLE 2 (SECONDS)	SAMPLE 3 (SECONDS)	SAMPLE 4 (SECONDS)	SAMPLE 5 (SECONDS)	SAMPLE 6 (SECONDS)	AVERAGE (SECONDS)
HANGERS FROM PALLET TO BLOCK	63	63	63	57	47	51	57.3
CHECK PAPERWORK	142	118	137	194	201	217	168.2
CALCULATE STANDOFF LENGTH	40	23	13	13	41	27	26.2
WALK TO SAW/CUT/WALK BACK	240	147	163	117	133	141	156.8
GRIND PAINT FROM HANGER	75	75	75	75	75	75	75.0
WELD ANGLE BAR TO HANGER	250	234	278	180	201	213	226.0
CUT LINER TO SUIT	18	17	21	11	9	14	15.0
RETRIEVE HANGER FASTENERS	30	30	30	30	30	30	30.0
WELD HANGER TO DECK	83	91	76	69	87	91	82.8
INSTALL LINER	18	12	14	11	12	9	12.7
INSTALL PIPE	22	37	37	37	41	41	35.8
INSTALL HANGER TOP & FASTEN	47	68	59	88	49	53	60.7
TOTAL TIME	1028	915	966	882	926	962	946.5
						TOTAL AVERAGE TIME	15.78 MINUTES

HANGER #2 INSTALLATION TASKS	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	AVERAGE
STUD LAYOUT	134	144	105	106	96	117
STUD FERRULE SETUP	23	30	22	32	45	30.4
SHOOTING STUDS/REMOVE SLAG	23	25	29	22	21	24
HANGERS FROM PALLET TO BLOCK	35	35	35	35	35	35
CHECK PAPERWORK	47	45	43	55	47	47.4
CUT STAND-OFF TO SUIT	64	47	77	47	39	54.8
REMOVE PROTECTIVE CAP	15	24	19	11	26	19
ATTACH STANDOFF TO STUD	37	49	63	35	28	42.4
CUT LINER TO SUIT	15	30	10	14	12	16.2
ATTACH HANGER HEAD TO STANDOFF	46	60	43	47	48	48.8
REMOVE PIN	5	7	6	8	5	6.2
INSTALL LINER	13	13	6	8	5	9
INSTALL PIPE	27	22	18	26	33	25.2
INSTALL PIN	19	25	35	42	19	28
		556	511	488	459	503.4
					TOTAL AVERAGE TIME	8.39 MINUTES

Figure 8 Hanger Installation Time Study Comparison Matrices

4.2. TOTAL INSTALLED COSTS DATABASE

It is recommended that databases be built containing the total installed costs that are made up from material, installation, fabrication and other such costs for future use. This database can be used as comparison data to evaluate and compare new products and installation techniques. This type of data is invaluable to eliminate any subjectivity from the product choices.

4.3. DIMENSIONAL LAYOUT FOR HANGERS

Traditionally, hangers are not dimensionally located on the drawing. Instead the centerline of the system is given on the detailed drawings. This is not a problem if the hanger is centered directly below the hanger. Hangers and the pipe, vent, and electrical systems are installed at the same stage of construction. This involves locating the pipe and determining from their where the hanger should land.

A new layout method would dimension the hangers, as opposed to the systems. From the model, locations of the hangers can be easily located on a hanger location drawing. This gives a much high degree of accuracy for hanger locations. The hangers then arrive on-block, pre-cut, for immediate installation at the Hot-Work stage of construction. The new methodology consists of installing the system to the hanger as opposed to the installing the hanger to the system.

Another layout method consists of using the 3-D model to get automated layout. This is done by downloaded the interface between the hangers and the structure to the N.C. tapes and from there to the N.C. burning machines.

Imbedding Expert Systems within the 3-D model environment.

This has the primary structure, foundations and hangering systems all being located from the same datum. Manual layout should be minimized. When designing racking systems or foundations on the same side as the primary structure, designers should utilize the primary structure to achieve layout. A fore/aft piping rack running on the underside of the deck should use the web-frames to give height and fore/aft dimensioning from the deck, with longditudinals to determine athwartship dimension.

4.3.1. N.C. LAYOUT HANGER MARKING SYSTEM

The A and B indicators shown above in the standard are modeled as part of the hanger in the 3-D model. These coordinate points are the data that is downloaded from the model to the N.C. burning tapes and from there onto the deck plates. A hanger numbering system should be in place, which would give the worker the simple task of matching up the hanger and N.C. layout identification numbers and welding out. It is recommended that the hanger be completely fabricated for immediate installation in the field with no field fabrication. This will assist in minimizing the block outfitting times.

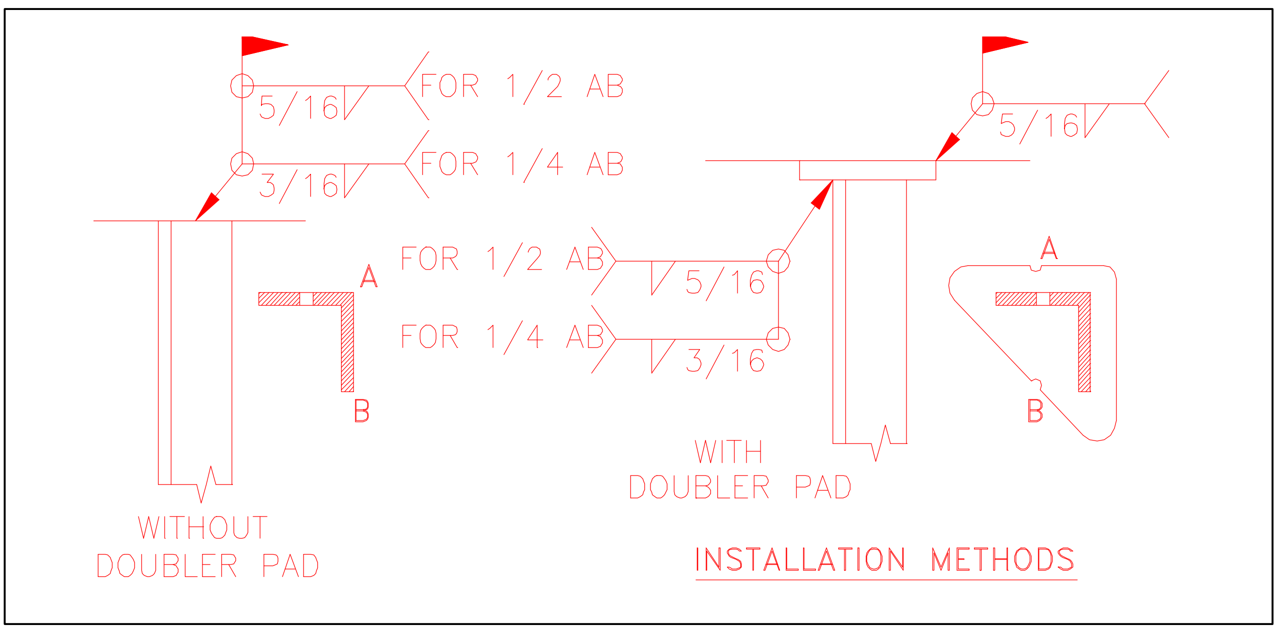


Figure 9 Hanger Layout System - 3-D Model To The Deck Plates

4.4. ATTACHMENT TECHNIQUES

The determination of which attachment technique should be used is determined mainly by which stage of construction the particular product will be installed in. A general rule of thumb is that hot work should be accomplished at the earlier stages and cold work for the later stages of construction.

During the early construction stages hot work (welding) is the primary task being performed. Therefore when it is beneficial to integrate outfitting into steel construction, welding should be adopted as the attachment technique for the outfitting products. This minimizes the amount of trades and services required at that stage and hot work damage to paint and insulation is not an issue.

During the later stages of construction hot work damage to other products becomes an issue. It is at these stages where the cold work attachment techniques should be considered for use.

4.4.1. HILTI SYSTEMS

Hilti Corporation has developed a number of fastening systems for industrial and marine applications that support the concept of quick attachment methods for shipboard use on foundations and system attachments. Their systems include Powder-Actuated Fastening, Screw Fastening Systems and Anchor systems. They have developed a channel installation system that will facilitate the lattice work system discussed previously. A description of the system components and some applications is included herewith.

Figure 10 Hilti Foundation Leg Installations This type of installation has various benefits. The panel can be used as a template to locate the stud locations. This is also a desirable method if this piece of equipment is planned to be installed after final paint.

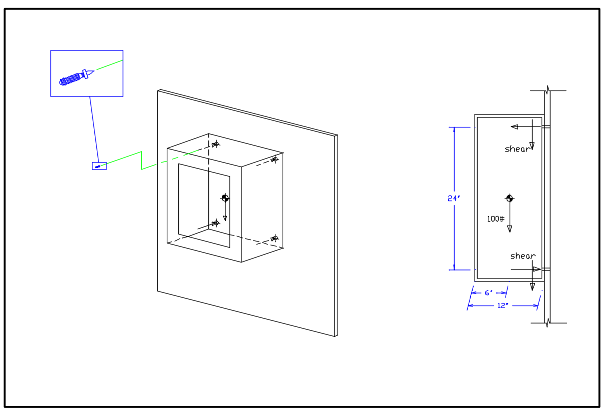


Figure 11 Typical Hilti Stud Installation

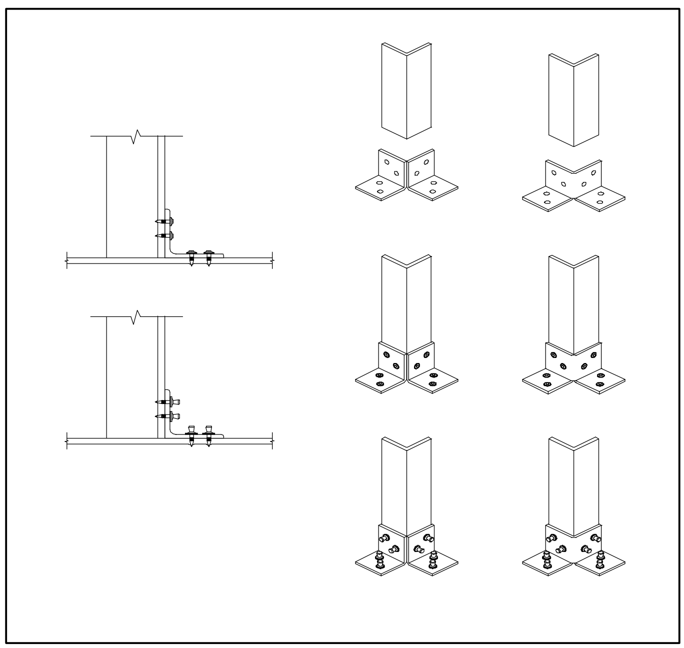


Figure 12 Stud Mounted Panel

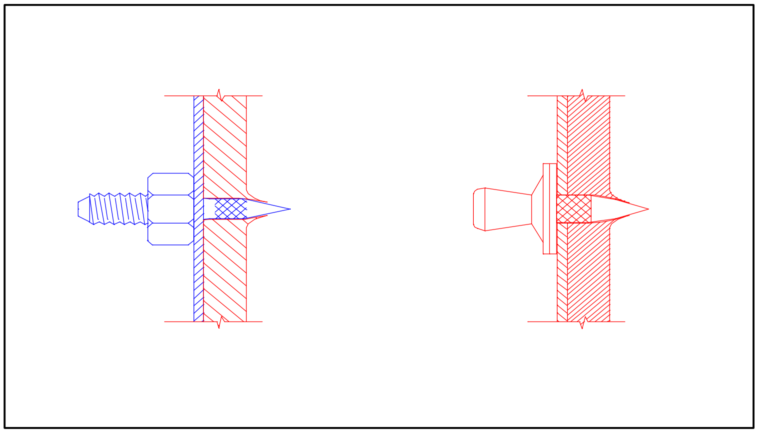


Figure 13 Typical Hilti Stud Attachments

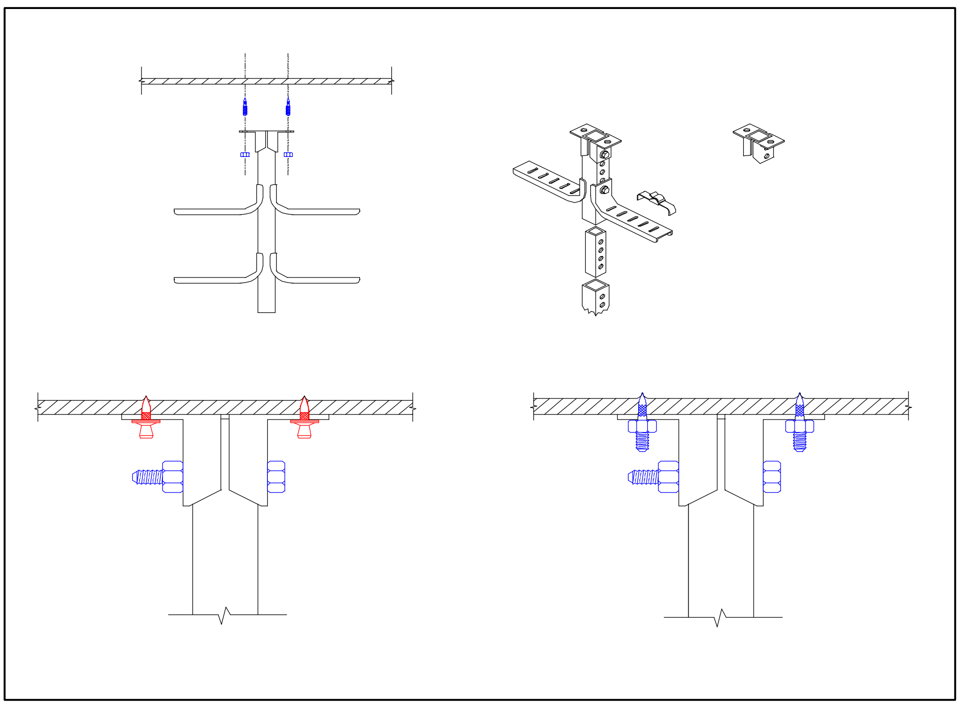


Figure 14 Hilti Stud Mounted Hanger Standoffs

4.4.2. FOUNDATION ATTACHMENT TECHNIQUES

The new techniques, methods and standards developed to suit both shop work and simplified outfit will integrate nicely with Simulation Based Design (SBD) and concurrent engineering to reduce overall engineering design time. The development of H, M&E systems installations to support a more competitive build strategy using the revolutionary H, M&E standards will achieve significant reduction in ship construction time and costs.

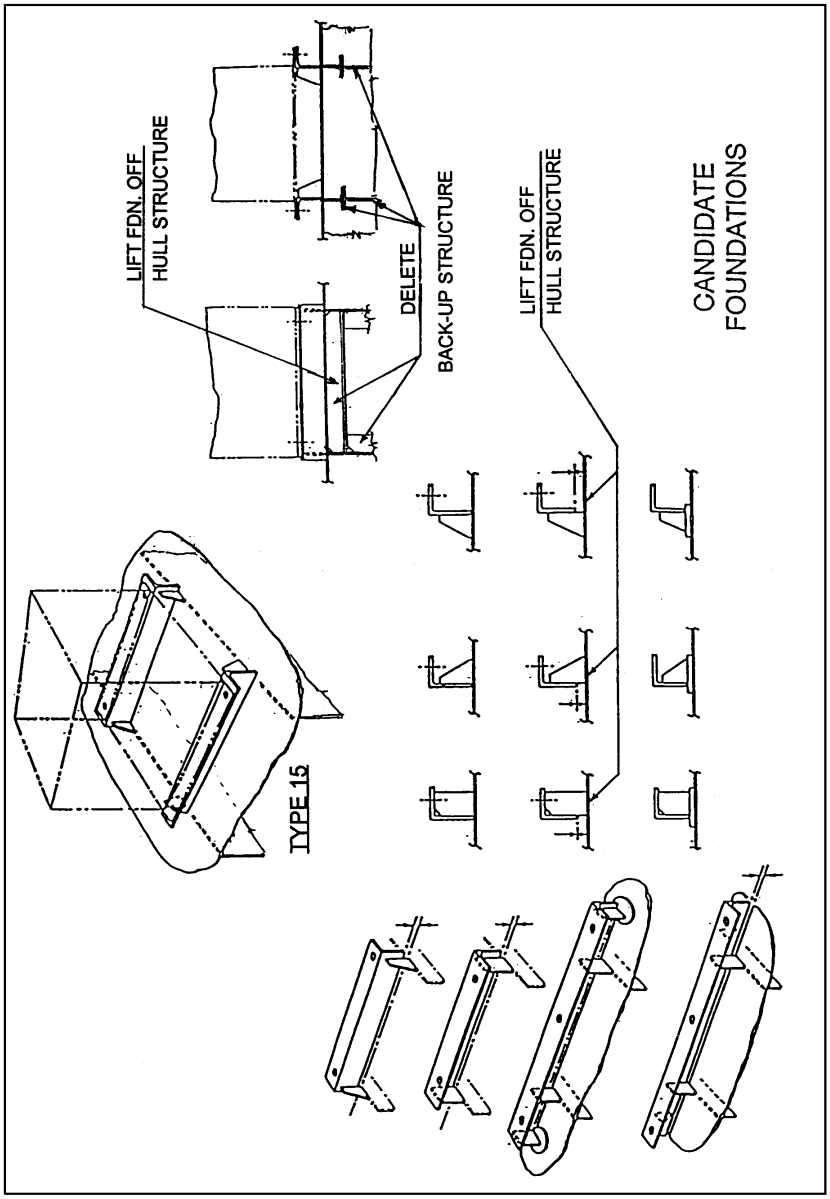


Figure 15 Alternative Foundation Attachment Techniques

4.4.3. SMART SYSTEM

Ship Modular Arrangement Reconfiguration Technology gives a high degree of interchangeability to on-board equipment installations. If smart system would be recommended when the on-board installation required the following criteria:

- Mission Flexibility.
- Number of anticipated changes to equipment in the projected ship life.

The following figures give an overview if the system with sample installations.

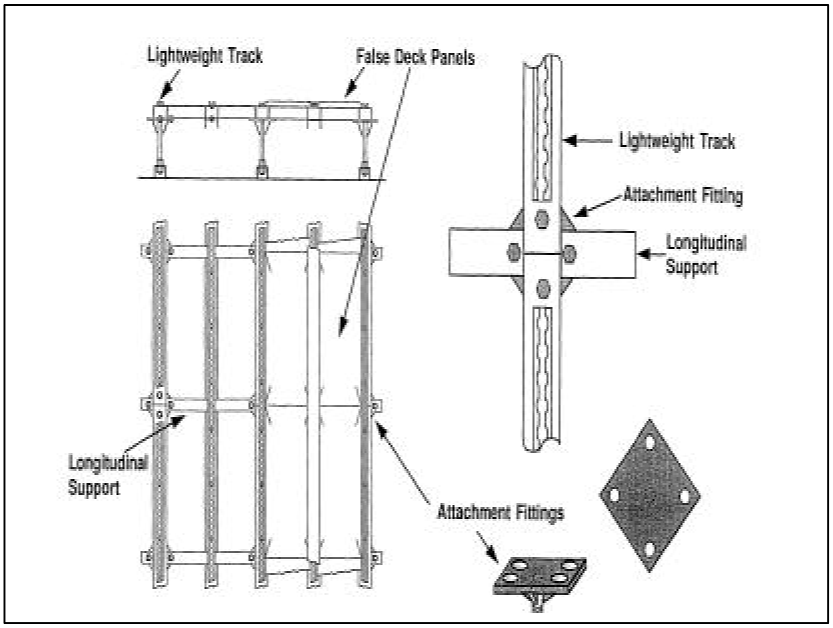


Figure 16 Lightweight "Softtrack" and False Deck Assembly

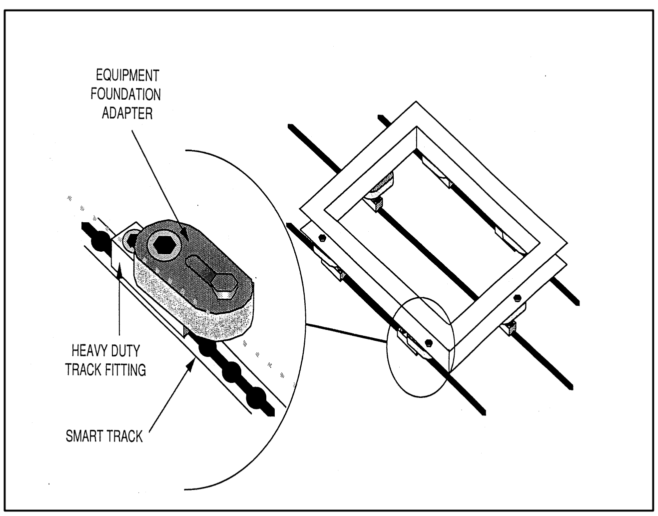


Figure 17 Medium/Heavy Weight Attachment and Fitting Assembly

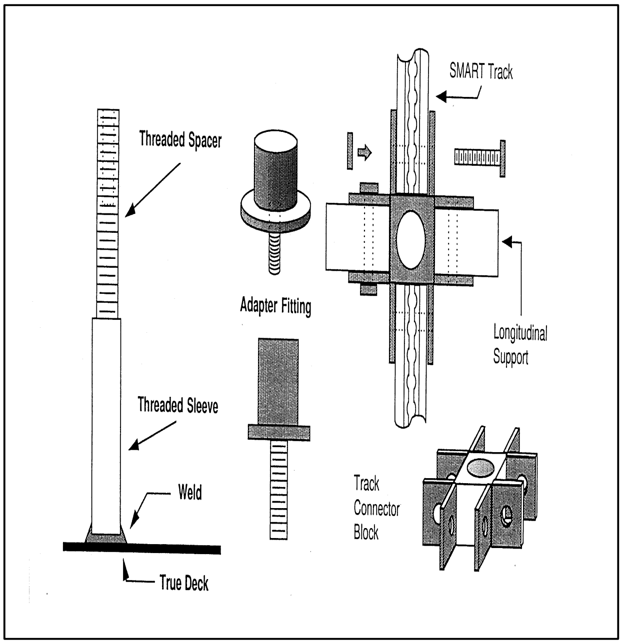


Figure 18 Typical Equipment Foundation With Track Fittings and Foundation Adapter

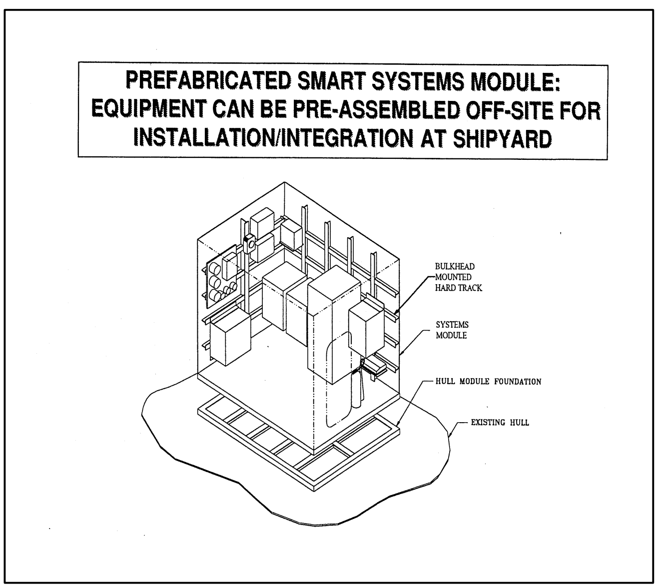


Figure 19 Prefabricated Smart Systems Module: Equipment Can Be Pre-Assembled Off-Site For Installation At Shipyard

4.4.4. TYPICAL SMART SYSTEM INSTALLATION

Determine candidate SMART deck spacing using modular track systems criteria matrix.

Perform deck/bulkhead survey to determine area & track orientation, and hard (mil. Spec.) versus soft track (cots) requirement.

Install track adapters.

Install SMART track.

Install longitudinal supports.

Install Deck panels/Filler Strips.

Install equipment foundation fittings and adapters.

Install equipment foundations and equipment.

4.5. ROBOTICS FOR EQUIPMENT AND SYSTEM INSTALLATIONS

4.5.1. OBJECTIVE

Develop applications for robots to assist the installation of equipment and systems, especially portable robots consistent with constraints imposed by robotic operations, construction accuracy standards and candidate hull structure and outfitting details.

4.5.2. BACKGROUND/APPROACH

Robots may be constrained to those details where it is relatively easy to achieve the construction accuracy standards necessary to successfully employ robots. In order to be effective, structural geometry accuracy must be maintained to close tolerances, typically less than 1/16 of an inch. However, it may be possible to broaden the use of robots through the use of standard construction details for both structure,outfitting and equipment and system installation standards and to hold the manufacturing of these details to tolerances that can support the use of "teach" robots. The use of teachable/programmable robots would employ the use of "Teach Pendants" in association with 3-D vision and software programming for the selected standards.

The standards would be programmed with the use of a 3-D product model that would describe the tool path for the robot, whether a welder or other tool that would be utilized to install the quick attachment fasteners that may be used for equipment and systems. The resultant MAP would be used by the robots 3-D vision system to guide the robot. The Teach Pendant would provide the robot with the initiation and termination of the welding, drilling or other operations sequence. The robot would compare the "standard" map of the weld/drilling/ops geometry with the 3-D vision of the actual weld/drilling/ops and make adjustments in the tool to account for differences (skewness and other characteristics) in order to complete the weld or other construction sequence.

The robot with 3-D vision capability will sense the fabrication geometry and tool path based on the software map of the standard structural or outfit detail. The Teach Pendant will orient the robot to its work, and would both provide where the weld will be initiated and where it will be terminated. Since the tool path will be based on a standard, increased flexibility can be built into the software controlling the ability of the robot to respond to the differences between the 3-D perceived geometry and the standard map geometry.

Since even standard parts are not identical, the robot must be programmed to adjust to an ever-increasing tolerance range on the set of geometrical data for each standard. Identification of current state-of-the-art geometry constraints for robots should be developed in association with robot manufacturers. Improvements in the ability of robots to follow programmable tool paths for standard structural and outfit details and make adjustments for actual distortions, skewness and irregularities will usher in advanced applications for robots.

4.5.3. TECHNICAL APPROACH

1. Identify Robotic operations, capabilities, and limitations in following prescribed tool path. Characterize state of the art in 3-D vision systems and teachable robots

2. Define parameters for the constraints on robots, standards, 3-D vision systems and teach pendant systems.

3. Identify Candidate structural standards and outfitting system equipment and system installation standards and applications that would be amenable to be constructed with portable robots.

4. Select Candidate structural/ outfitting details, portable robotic systems, 3-D vision systems and teachable control systems to develop candidate applications for portable robotic systems.

5. Develop selected standards for portable robots using 3-D vision systems and teach pendants. Program software tool paths for the advanced portable robots using newly developed standards.

6. Develop demonstrations of portable robotics for candidate structural/ outfitting standards.

5. PILOT PROGRAMS

When products were considered for implementation to the standard a Pilot was run before full implementation. The pilot included collecting material costs, fabrication costs, along with doing time studies for installation. This gave a total installed cost for each product. The focus was on reducing cycle time along with minimizing total cost. Running the pilot gives a comfort level when selecting one product over another.

5.1. CENTRAL KITTING AREA

A central kitting area is required to assemble complete hanger assemblies, which are cut to suit, and deliver then ready for installation. The idea is to have the worker on-block or on-board to be installing the hangers only. Removing any cutting or assembling from the installation area which increases the throughput of the block. This in turn reduces the cycle time to build a ship.

6. CONCLUSION

The use of the standards, attachment techniques and processes for equipment foundations and hangering systems for distributive system outlined in this project will have a dramatic effect reducing the overall construction time of the ship

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Additional copies of this report can be obtained from the National Shipbuilding Research and Documentation Center:

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